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Advanced Missions Safety

Volume I: Executive Summary

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Prepared by
SYSTEMS PLANNING DIVISION

15 October 1972

Prepared for
OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASw-2301

Systems Engineering Operations
THE AEROSPACE CORPORATION

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VOLUME I - EXECUTIVE SUMMARY

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Volume I: Executive Summary

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PREFACE

The study on Advanced Missions Safety was performed as Task 2.6 of Contract NASw-2301 entitled, "Advanced Space Program Analysis and Planning." The task consisted of three subtasks:

Subtask 1 - Space Shuttle Rescue Capability (Vol. II-1 and Vol. III-1)
Subtask 2 - Experiment Safety (Vol. II-2 and Vol. III-2)
Subtask 3 - Emergency Crew Transfer (Vol. II-3)

Each subtask is an independent entity and is independent of the other two subtasks.

The results of this study are presented in three volumes.

<u>Volume I</u>: <u>Executive Summary Report</u> presents a concise review of the results, conclusions, and recommendations for all three subtasks.

<u>Volume II</u>: <u>Technical Discussion</u> is in three parts, each presenting a comprehensive discussion of a single subtask.

<u>Volume III</u>: <u>Appendices</u> contains detailed supporting analysis for Subtasks 1 and 2 and is of interest primarily to the technical specialist.

The Advanced Missions Safety Task was sponsored by NASA Headquarters and was managed by the Advanced Missions Office of the Office of Manned Space Flight. Mr. Herbert Schaefer, the study monitor, provided guidance and counsel that significantly aided the total effort. Mr. Charles W. Childs of the Safety Office, NASA Headquarters, and Miss Ruth N. Weltmann of the Aerospace Safety Research and Data Institute, NASA-Lewis, also provided valuable comments and suggestions.

VOLUME I

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FIGURES

1. INTRODUCTION

Three separate studies were performed under the general category of "Advanced Missions Safety." Each dealt with a separate issue, was a self-contained effort, and was independent of the other two studies. The studies are titled:

A. Space Shuttle Rescue Capability
B. Experiment Safety
C. Emergency Crew Transfer

A separate discussion of each study follows.

2. RELATIONSHIP TO FUTURE NASA PROGRAMS

2.1 SPACE SHUTTLE RESCUE CAPABILITY

This study contributes preliminary information on using the Space Shuttle for space rescue missions in the time frame when men will be placed in orbits which are beyond the design capability of the basic Space Shuttle.

2.2 EXPERIMENT SAFETY

The safety guidelines developed in this study provide safety inputs into all phases of the in-space experiment program associated with the Space Shuttle, with particular emphasis on the integration of experiments and their equipment with Experiment Modules and the Orbiter and their potential hazardous interactions.

2.3 EMERGENCY CREW TRANSFER

The output of this study is intended to provide basic data for planning in-space emergency equipment for transfer of men from a distressed vehicle to a space rescue vehicle.

3. SPACE SHUTTLE RESCUE CAPABILITY

3.1 STUDY OBJECTIVE

The objective of this study was to examine the feasibility of extending the rescue mission utility of the Space Shuttle beyond its presently planned performance capabity.

3.2 SCOPE

Three general methods of increasing the basic Shuttle capability were examined:

a. Increased propellant loading at lift-off (cargo bay tank)
b. Orbital refueling
c. Shuttle-launched Tug (single Tug and tandem Tugs)

Four different Space Shuttle configurations were initially analyzed. Only the results of an add-on effort which considered the configuration specified in the Space Shuttle RFP, released after the initial study effort was completed, are reported herein.

Based on a previous study the weight of a typical rescue payload was assumed to be 10 klb (4.5 t).

3.3 RESULTS

Of the several designs examined, the drop tank Orbiter configuration as specified in the Space Shuttle RFP provides the best overall rescue mission capability. A summary overview of the conclusions reached for this configuration is given in Figure 1.

Cargo Bay Tank

Increasing the lift-off propellant loading by means of a cargo bay tank is useful primarily in low earth orbit. An additional ΔV of approximately 2 kft/s (0.6 km/s) could be provided for a due east launch with which the Orbiter could reach an orbital altitude of about 800 nmi (1,500 km).

Augmentation Mode		Emergency P/L		Added ΔV		Added Round Trip Capability	Remarks
Added Orbiter Propellant	Tug in Cargo Bay	klb	(t)	kft/s	(km/s)		
Cargo Bay Tank	--	10	(4.5)	~ 2	(~0.6)	Orbiter to ~800 nmi (1,500 km)	
Orbital Refueling	--	10	(4.5)	29	(8.8)	Orbiter to Lunar and Geosynchronous Orbits	
	--	70	(32)	26	(7.9)	Orbiter to Lunar and Geosynchronous Orbits	Orbiter Returns Via Multiple-Pass Grazing Reentry
--	Yes	10	(4.5)	~22	(~6.7)	Tug to 12,000 nmi (22,000 km)	Equivalent to 50° Plane Change in Low Earth Orbit
--	Yes	< 5	(<2.2)	29	(8.8)	Tug to Lunar and Geosynchronous Orbits	Tug Returns to Low Earth Orbit
--	Tandem Tug	10	(4.5)	29	(8.8)	Tug to Lunar and Geosynchronous Orbits	Both Tugs Return to Low Earth Orbit

Figure 1. Shuttle Rescue Capability Summary

Orbital Refueling

Both lunar and geosynchronous orbit round trips from low earth orbit appear marginally possible with a 10 klb (4.5 t) rescue payload by refueling the Orbiter drop tank in low earth orbit. Further, if Orbiter refueling is combined with an added cargo bay propellant tank, some maneuvering capability in the rescue orbit is achieved.

The refueled Orbiter can even deliver a 70 klb (32 t) payload into either lunar or geosynchronous orbits. The remaining ΔV is not sufficient, however, to return the Orbiter and payload to low earth orbit. Since the Orbiter is not designed for direct reentry from such high energy missions, an alternate earth return technique such as multiple-pass grazing reentry must be considered. Current Orbiter thermal protection system designs and radiation shielding appear adequate for multiple-pass grazing reentry without limiting the crossrange capability.

Orbiter-Launched Tug

Carrying a fueled Tug with an attached rescue payload (which could be manned) in the Orbiter cargo bay and launching it from a 100 nmi (185 km) orbit would be useful for:

- Low earth orbit emergencies

  With a Tug ΔV of about 22 kft/s (6.7 km/s) and carrying a 10 klb (4.5 t) emergency payload, a round trip capability to a 12,000 nmi (22,000 km) orbit is attainable.

- Lunar/geosynchronous orbit emergencies

  The Tug has a round trip capability of <5 klb (2.2 t). With a Tandem Tug which requires two Shuttle launches, the emergency payload could be raised to 10 klb (4.5 t).

3.4 CONCLUSIONS

For use as a space rescue vehicle, the Space Shuttle performance capability can be increased by any of the three methods considered:

- The addition of a cargo bay tank is a relatively simple method and would result in a performance capability to an orbit of about 800 nmi (1,500 km).
- Orbital refueling could extend the Orbiter performance capability to lunar and geosynchronous orbits. It is unlikely, however, that this augmentation mode would be acquired solely to meet rescue mission requirements. In addition to the large cost of the additional equipment involved, the time required to refuel the Orbiter main propellant tank is excessively long for a rescue mission. About 30 Shuttle flights would be required for a single refueling operation unless a propellant depot were available or the empty Orbiter tank could be exchanged for a fueled tank already in orbit.
- Carrying a Tug and rescue payload in the cargo bay for launch from low earth orbit could be useful for emergencies in low earth orbit. The payload capacity is insufficient, however, for lunar and geosynchronous orbits. Such missions would require a Tandem Tug configuration.

4. EXPERIMENT SAFETY

4.1 STUDY OBJECTIVES

The objectives of the study were:

a. Analyze the potential emergency situations created by carrying experiment equipment aboard a Space Shuttle.

b. Identify safety guidelines and requirements for eliminating or reducing hazards to the Space Shuttle and its crew which may be introduced by the experiment equipment and its operation.

4.2 STUDY SCOPE

The safety analysis considered all mission phases from the launch pad through to deployment, free flight (where applicable), experiment operations, retrieval, and final disposition. Also considered were the interactions of the experiment equipment and experiment operations with Experiment Modules (Pallet, MSM, RAM, Sortie Module, etc.) and the Space Shuttle, other payloads within the Orbiter cargo bay, and associated satellites.

The analysis was based on experiments identified in the Blue Book and in the SOAR study.

4.3 DISCUSSION

The large variety of experiments aboard an Orbiter on any one flight could create many potential hazards because of the interaction between the Experiment Equipment and its operations, Accommodation Modules, experimenters, and Shuttle Orbiter operational equipment and crew. Malfunctioning Experiment Equipment presents discrete hazard sources; the potential hazards created by them could propagate to other Experiment Equipment and supporting equipment and to operational equipment of the Accommodating Module and the Orbiter.

In contrast to safety considerations in experiment ground facilities, which emphasize experimenter safety first, an experiment laboratory in space has to give prime safety considerations to the operational functioning of the Orbiter to enable a safe crew return.

In ground facilities, hazardous experiments are separated from other experiments and personnel. For space operations, experiment equipment of a hazardous nature may be densely packed, because flight costs are high. For this reason, special attention has to be given to potential interferences and interactions such as overheating, permeating fields (RF transmitters, X-ray machines, high-powered magnets, lasers, etc.), spurious signals, high-voltage potential (TV, inverters, pulsers, etc.), etc. Such interaction between experiments could lead to a malfunction of otherwise safe equipment and might influence the safe operation of the Orbiter.

Many hazardous materials on board the Orbiter, such as cryogenics, storable propellants, film, processing chemicals, plastic and nuclear emulsions, toxic serums, radioisotopes, etc., will add to the hazards of some of the experiments and the crew. The location of such materials in relation to any experiment or Orbiter equipment, as well as the access and egress routes for the experimenters, requires serious consideration.

In contrast to most ground laboratories, the Orbiter structure outside the crew compartment can withstand a pressure difference of only a few psi. Therefore, experiments with components of a potential high-pressure or explosive source (gas bottles, liquid and solid propellants, etc.) have to be constrained, shielded, or safed to prevent inadvertent activation by other experiments.

Toxic and hazardous materials (bacteria, isotopes, biologicals, mercury, processing chemicals, etc.), especially in gaseous or powder form, which present a health hazard to men or which can damage materials or equipment,

may have to be double-contained with special environmental conditioning systems, as complete cleanup of contaminants in zero gravity might be impossible to achieve.

Many of the experiments being considered have high-voltage components (TV, imaging tubes, inverters, pulsers, etc.) with the potential of fire, shock, etc., which could result in injury to the crew and damage to the Orbiter. The clear indication of the operational status of such components is required. In case of emergency, provisions for automatic shutdown and rapid discharge after shutdown are required. Ground circuits should be avoided.

Emergency situations resulting from experiment equipment and/or its operation that could lead to Orbiter damage and/or loss require immediate assessment by the Orbiter crew. This can be accomplished by providing warning signals in the crew compartment which indicate the hazard, its severity, its location, etc. Normal procedures provide the commander with the authority to determine actions necessary to save the Orbiter and crew. This may involve sacrificing an experiment, an Experiment Module, and perhaps even a crew member, if the emergency warrants such drastic means and the Orbiter and most of the crew can be saved by such an action.

Radiation sources such as radioisotopes, X-rays, lasers, etc. which can cause injury to men and damage to materials, equipment, experiments, and the operation of the Orbiter should be clearly marked, monitored, shielded, and located so that no interference is possible under normal operating conditions. Emergency procedures and plans should be prepared and executed, if an emergency or malfunction is indicated by the monitoring system.

Where a number of experiments might be operated simultaneously, safety procedures should consider not only single experiments but also the

interactions of all experiments to be operated at any one time. A certain shutdown procedure might be safe for one experiment but might create an emergency situation in another experiment, thus endangering the Orbiter and crew.

In the case of hazardous experiment equipment, such as lasers, combustors, furnaces, propellant transfer systems, and X-rays, there should be a trade-off study made to determine whether the experiment should be conducted within or exterior to the Experiment Module or Orbiter. If located within the Experiment Module, the experimenter can closely supervise the experiment operations and ensure compliance with all safety procedures. If located exterior to the Module or Orbiter, docking or EVA may be required. Such operations also have safety implications, such as collisions and EVA hazards.

4.4 CONCLUSIONS

The safety effort related to experiments associated with a Space Shuttle Orbiter requires an integrated system approach which covers essentially three system levels:

a. Experiment Equipment design

b. Integration of Experiment Equipment within an Accommodation Module

c. Integration of an Accommodation Module within the Orbiter

Emphasis must be given in all these interrelated safety efforts to potential experiment operational hazards due to synergistic interactions of the Experiment Equipment with other Experiment Equipment and with Orbiter systems.

The study identified 164 general and specific experiment Safety Guidelines which cover the entire experiment mission spectrum from the launch

pad through deployed experiment operations to Orbiter landing. For visibility each Guideline is identified as to its applicability to:

- Experiment and/or Experiment Equipment
- The interface of the Experiment to the Orbiter or the Accommodation Module
- The Orbiter
- Experiment Modules
- Four areas of the mission spectrum

Locational Safety Guidelines have been identified in addition to the conventional design and operational Safety Guidelines. This new classification is needed for experiment safety because Experiment Equipment will be developed in many cases long before its location on board an Orbiter flight has been established, and the integration effort in levels (b) and (c) mentioned above may be influenced by potentially hazardous interface conditions stemming from the Experiment and/or its equipment.

These Safety Guidelines will be useful as checklists and as inputs into the design, integration, and planning phases of Space Shuttle experiments. Such inputs are needed for obtaining "Man-Compatibility" between Experiments and their operation with the Orbiter.

These are initial safety guidelines, commensurate with the current limited definition of Experiments. As the level of definition of Experiments increases, the guidelines should be expanded to be consistent with the specific equipment to be used.

5. EMERGENCY CREW TRANSFER

5.1 STUDY OBJECTIVE

The objective of this study was to assess and compare the relative effectiveness of possible rescue configurations for emergency crew transfer from a Distressed Vehicle (DV) to a Space Rescue Vehicle (SRV) while the two vehicles are not docked to each other (see Figure 2). Factors such as unique capabilities, limitations, ease and speed of use, applicability, and development and procurement costs were to be considered.

Figure 2. Schematic Diagram of Region of Study Interest

5.2 SCOPE

The evaluation of emergency transfer means was limited to the following operations:

- EVA
- Space Shuttle Orbiter
- Space Station
- Research Applications Module (RAM)

Characteristics of the transfer means were based on information in the available literature.

The feedback effect of the transfer device on the design and cost of the spacecraft on which it will be carried and/or used was beyond the scope of this study.

5.3 DISCUSSION

5.3.1 General

The assessment made in this study was essentially subjective. Costs were estimated from available conceptual designs. In addition, the effect of a transfer device on the parent spacecraft was not considered. In spite of such limitations, a reasonably valid indication was obtained of the capability preference among transfer devices as a function of dollar expenditure.

Emergency transfer devices identified in earlier studies generally fall into one of the following categories:

- Unassisted EVA

  An individual crewman wearing a pressure suit and moving under self power.

- Augmented Unassisted EVA

  An individual crewman wearing a pressure suit and moving by means of a separate impulse source under his control.

- Assisted EVA

  A suited DV crewman aided in traversing the standoff distance by externally provided means not under his control.

- Pressurized Transfer Vehicle

  Devices which shuttle between the DV and the SRV and carry an operating crew plus passengers.

- Special Purpose Devices

  Devices which can be used for emergency transfer of personnel from the DV and the SRV.

The Pressurized Transfer Vehicle category can generally handle the entire disabled vehicle crew. All other categories can handle only one to two men at a time.

The features of each category were characterized, and then the crew emergency transfer utility of each category was ranked against selected operating criteria. A range of estimated development and manufacturing costs was also established for each category.

5.3.2 Design and Operational Characteristics

A summary of the design characteristics for typical emergency transfer devices is given in Figure 3. Except for the Pressurized Transfer Vehicle (PTV) category, the characteristics of each of the five categories fall into a reasonably narrow range. Since significant differences are noted between a PTV based at a DV and a PTV based at an SRV, both subcategories were separately identified.

The operational characteristics of the five general transfer categories are given in Figure 4. With this information and that contained in Figure 3, a basis was established for ranking the relative effectiveness of the individual transfer categories.

5.3.3 Transfer Category Comparison

Although specific criteria can be identified as influencing the applicability of a transfer category, quantifying these criteria is largely a subjective process.

The criteria from which the operational effectiveness was established are given in Figure 5 together with the weighting factors and the score for each category.

The most effective category, although not necessarily an ideal solution, was rated 10. The least effective category was rated 2. (A completely ineffective situation would be scored 0.) All other categories are scored between these values according to their estimated effectiveness.

By applying the assigned weighting factor for each criterion to the individual category score, a total rating for each transfer category was established.

Configuration	Where Based	Stored Unit Wt.		Stored Unit Volume		Capability		Operating Duration hr	Atmosphere		
		lb	(kg)	ft^3	(m^3)	Passenger	Crew		Composition	Pressure psia	Pressure (ata)
Unassisted EVA											
IVA Suit	DV	15	7	1	0.03	1	-	1 - 4	100%O_2	8	0.6
EVA Suit	DV	65	30	4.5	0.13	1	-	4 - 8	100%O_2	8	0.6
Augmented Unassisted EVA											
AMU	DV	150	70	4	0.11	1	-	4 - 8	100%O_2	8	0.6
Work Platform	DV	500	230	30	0.85	1 - 2	-	4 - 8	100%O_2	8	0.6
Assisted EVA											
Buddy (with AMU)	SRV	65+150	30+70	4.5+4	0.13+0.11	1+	1	4	100%O_2	8	0.6
RMU (unmanned)	SRV	150	70	4	0.11	1	-	>4	-	-	-
Space Flyer	SRV	865	390	85	2.4	1 - 2	1	4 - 8	100%O_2	8	0.6
Maintenance Capsule	SRV	2,000	910	70	2	1	1	24 - 48	SL	14.7	1
Pressurized Transfer Vehicle											
Bailout and Wait	DV	6,700	3,000	NA	NA	15	-	48	SL	14.7	1
Bailout and Transfer	DV	18,500	8,400	NA	NA	15	-	120	SL	14.7	1
Manned Tug	SRV	72,000	33,000	7,500	210	12	3	48	SL	14.7	1
Crew/Cargo Module (with propulsion)	SRV	21,000	9,600	2,000	57	12	3	48	SL	14.7	1
Maintenance Capsule	DV	2,000	910	70	2	2	-	24 - 48	SL	14.7	1
Special Purpose Devices											
Expandable Transfer Capsule	SRV	500	230	50	1.4	2	-	8	SL	14.7	1
Portable Airlock	SRV	1,600	730	380	11	2	-	24	*	*	*
Apollo Soyuz Docking Module	SRV	3,360	1,524	200	5.7	2	-	~24	Variable		

*Operated from SL to 100% O_2 @ 8 psia (0.6 ata)

Figure 3. Transfer Device Design Characteristics Summary

Characteristic	Transfer Categories				
	Unassisted EVA	Augmented Unassisted EVA	Assisted EVA	Pressurized Transfer Vehicle	Special Purpose Devices
Capacity	1	1	1-2	12-15	2
Storage site	DV	DV	SRV	SRV	SRV
Operated by	DV crew	DV crew	SRV crew	SRV crew	DV and SRV crews
Personnel in EVA	DV crew	DV crew	DV and SRV crews	None	SRV crew
DV crew dependence	Self-dependent	Self-dependent	Assisted	Assisted	Assisted
Added DV crew stress	Very great	Great	Moderate	None	Moderate
Mobility	Self-power	Auxiliary impulse source	Externally provided and controlled	Self-contained	Externally provided and controlled
Standoff distance	Negligible	to 2 - 4 km	to ~ 2 km	> 2 km	< 2 km
Operating duration	4 - 8 hours	4 - 8 hours	4 + hours	48 hours	8 - 24 hours
Environment	Pressure suit	Pressure suit	Pressure suit	Shirtsleeve	Shirtsleeve
Atmosphere	8 psia (0.6 ata) 100% O_2	8 psia (0.6 ata) 100% O_2	8 psia (0.6 ata) 100% O_2	Sea level	Sea level
Source of life support	Backpack or umbilical	Backpack	Backpack or portable ECLS	Self-contained ECLS	Self-contained ECLS
Injury accommodation	None	Slight	Moderate	Major	Major
Use with foreign spacecraft	Yes	Yes	Yes	Limited	Limited
Added skills/training	Minimal	Yes (DV crew)	Yes (SRV crew)	Yes (SRV crew)	Yes (DV and SRV crews)
SRV requirement	Receive EVA personnel	Receive EVA personnel	Discharge and Receive EVA personnel	Docking Fixture	Docking Fixture and Discharge and Receive EVA personnel

Figure 4. Transfer Category Operational Characteristics Summary

Weighting Factor	Criteria	Unassisted EVA	Augmented Unassisted EVA	Assisted EVA	Pressurized Transfer Vehicle		Special Purpose Device
					At DV	At SRV	
0.30	Emergency Effectiveness	2.9	6.1	6.3	10	8.3	5.7
0.15	Operational Characteristics	2	6	4	10	10	5
0.10	Capacity	2	4	5	10	10	6
0.10	Availability When Emergency Occurs	10	9	6	8	5	2
	Exposure to Danger						
0.05	- DV Crew	2	3	4	9	10	7
0.10	- SRV Crew	10	10	3	10	7	2
0.05	Use Skills Index	10	9	7	3	2	5
0.05	Multiple Usage	4	10	2	8	8	6
0.10	Foreign Spacecraft Accommodation	10	10	8	7	2	6
1.00							

Figure 5. Score Tabulation for Operational Effectiveness

The transfer categories are ranked in Figure 6 according to this total weighted score, normalized to a maximum value of 10.

Rank	Transfer Category	Normalized Score
1	Pressurized Transfer Vehicle Based at DV	10.0
2	Pressurized Transfer Vehicle Based at SRV	8.2
3	Augmented Unassisted EVA	7.9
4	Assisted EVA	5.9
5	Unassisted EVA	5.8
6	Special Purpose Device	5.5

Figure 6. Rank Based on Operational Effectiveness

The estimated range for both RDT&E and First Unit Manufacturing Cost are listed in ascending plateaus in Figure 7.

Transfer devices requiring a new hardware development can be economically assessed on the basis of their RDT&E cost. Transfer devices based on hardware already available and developed to meet a non-rescue requirement can be economically assessed on the basis of their first unit manufacturing cost.

EVA can be involved in all categories and is required for most. If an advanced pressure suit is developed to meet non-emergency requirements, however, or if each spacecraft is equipped with an individual suit for all personnel, then suit costs ought not be assessed against emergency transfer cost. Therefore, data are presented in Figure 7 both with and without pressure suit costs. Also included in Figure 7 is the operational effectiveness rank from Figure 6.

Operational Effectiveness Rank	Transfer Category	Cost (million 1970 dollars)			
		RDT&E		First Unit Mfg.	
		Including Pressure Suit	Without Pressure Suit	Including Pressure Suit	Without Pressure Suit
5	Unassisted EVA	40 - 50	0	* 1 - 2	0
6	Special Purpose Devices	69 - 94	29 - 44	2.6 - 4	1.6 - 2
3	Augmented Unassisted EVA	75 - 100	25 - 50	* 2 - 4	1 - 2
4	Assisted EVA	101 - 175	51 - 175	* 4† - 11	1 - 9
1	Pressurized Transfer Vehicle at DV	204 - 380	164 - 330	10 - 20	9 - 18
2	Pressurized Transfer Vehicle at SRV	>450	>400	21 - 40	20 - 38

*Cost per man

†Includes EVA suit for SRV crewman and IVA suit for DV crewman

Figure 7. Cost Plateau Comparisons

5.4 CONCLUSIONS

A crew transfer device based at a Distressed Vehicle is generally preferred to one which originates at the rescuing spacecraft. Thus, a Pressurized Transfer Vehicle based at the Distressed Vehicle had the best score. However, since costs increase with transfer technique complexity, it was concluded that Augmented Unassisted EVA (which transfers one to two men at a time) offers the best solution at moderate cost for a small crew. But if a Pressurized Transfer Vehicle has been developed to meet non-emergency needs, then it is not only operationally preferred but it is most cost effective for transferring a large crew (>8 crewmen) as well.

Augmented Unassisted EVA will involve an estimated development cost of \$25 to \$50 million (excluding pressure suit development), whereas a Pressurized Transfer Vehicle will have an estimated development cost of \$164 to \$330 million. If developed for other, non-emergency needs, the first unit manufacturing cost is estimated at \$1 to \$2 million for Augmented Unassisted EVA (carrying 1 or 2 men) and \$9 to \$18 million for a Pressurized Transfer Vehicle (capable of carrying up to 15 men).

The Docking Module for the Apollo-Soyuz Test Project falls into the Special Purpose Device category and is potentially useful for emergency crew transfer.